OPTIMAL TIME AND ENERGY EFFICIENCY IN LEGGED ROBOTICS

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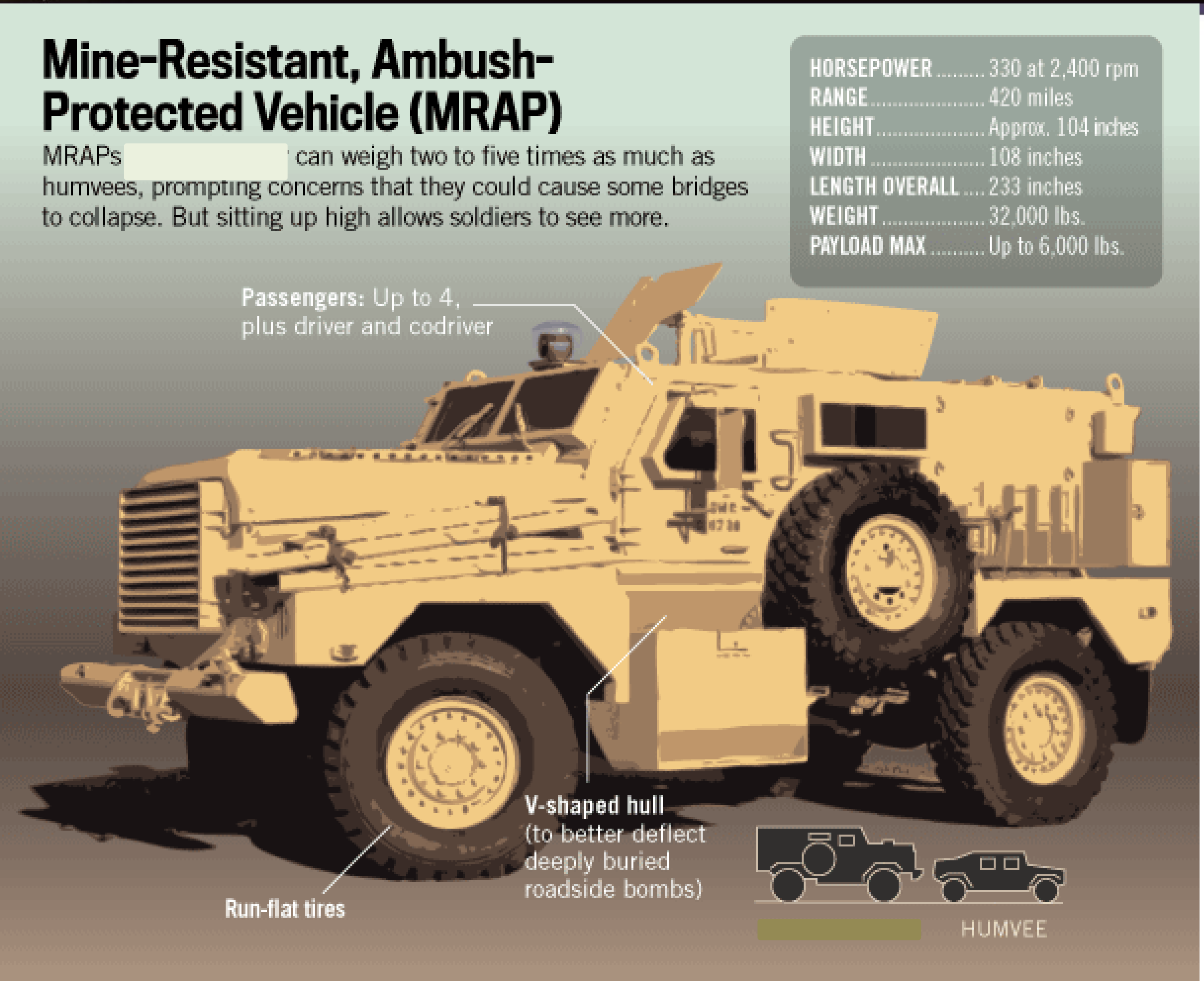
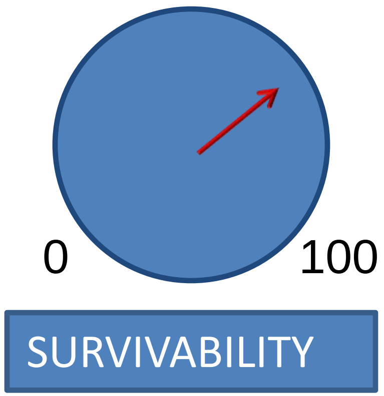
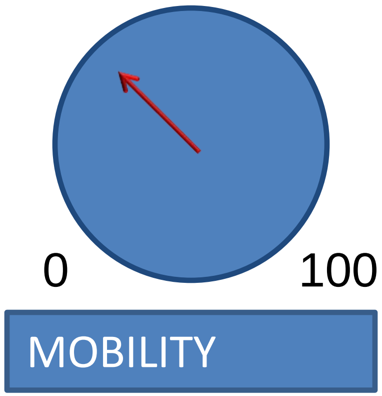
OPTIMIZATION

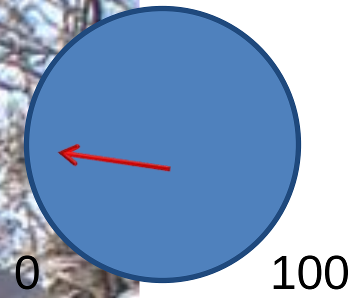
ROBOTIC SYSTEMS



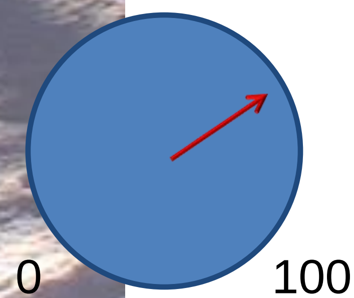




OPTIMIZATION



EFFICIENCY



MOBILITY

CONTENTS

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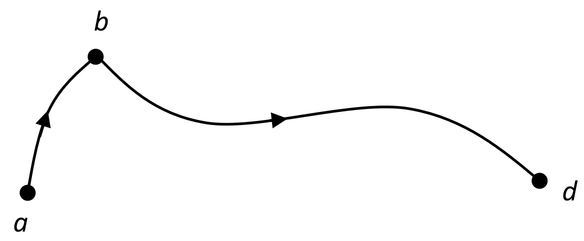
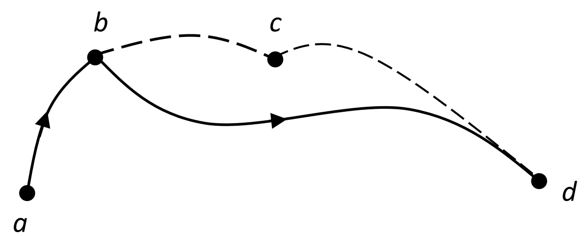
- OPTIMAL CONTROL
  – POYNTRYAGIN'S MAXIMUM PRINCIPLE
  – DYNAMIC PROGRAMMING
- EXAMPLE: SWITCHING CURVE IN POWERED PENDULUM
- HARDWARE IMPLEMENTATION
- CONCLUSIONS & FUTURE WORK

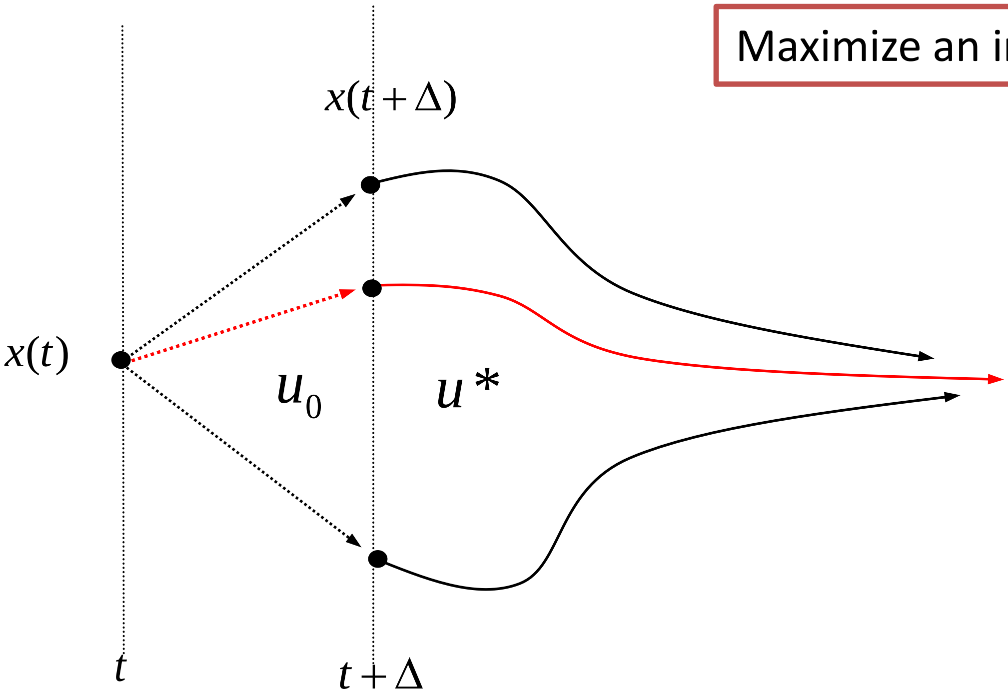
PRINCIPLE OF OPTIMALITY



If *a*-*b*-*d* is the optimal path from *a* to *d*, then *b*-*d* is the optimal path from *b* to *d*.



POYNTRYAGIN MAXIMUM PRINCIPLE



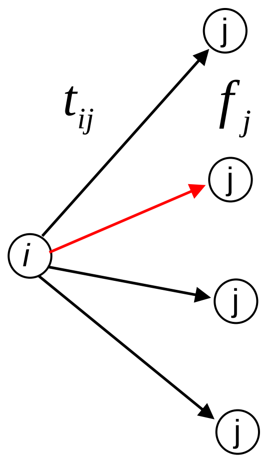
Maximize an integral-type cost

$$J[x_0,\vec{u}] = \int_0^T \phi(x,u)dt$$

vs.

$$J^*(x_0) = \max_u J\left[x_0,\vec{u}\right]$$

DYNAMIC PROGRAMMING



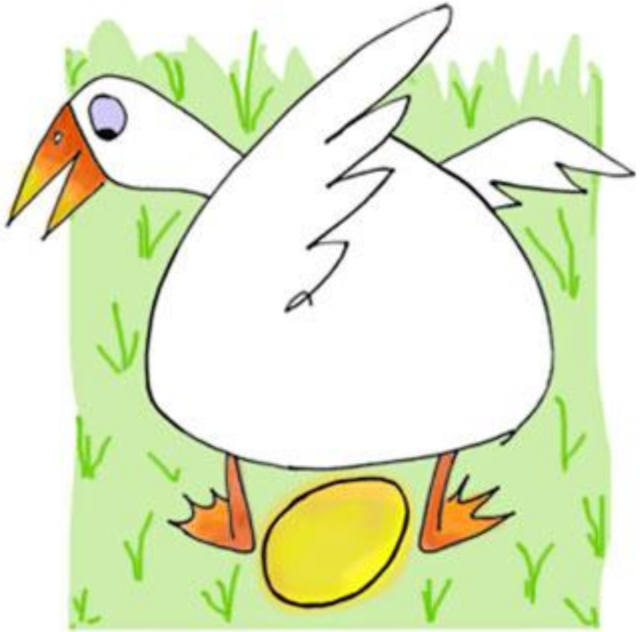
Minimize (-max) over all possible arcs (i, j)

$$f_i = \min_j \left\{ t_{ij} + f_j \right\}$$

t_{ij} = cost of the directed arc (i, j)

f_i = min travel time from node i to end

GOOSE VS. GOLDEN EGGS



Revenue produced

$$\phi(x,u)$$

vs.

Value added

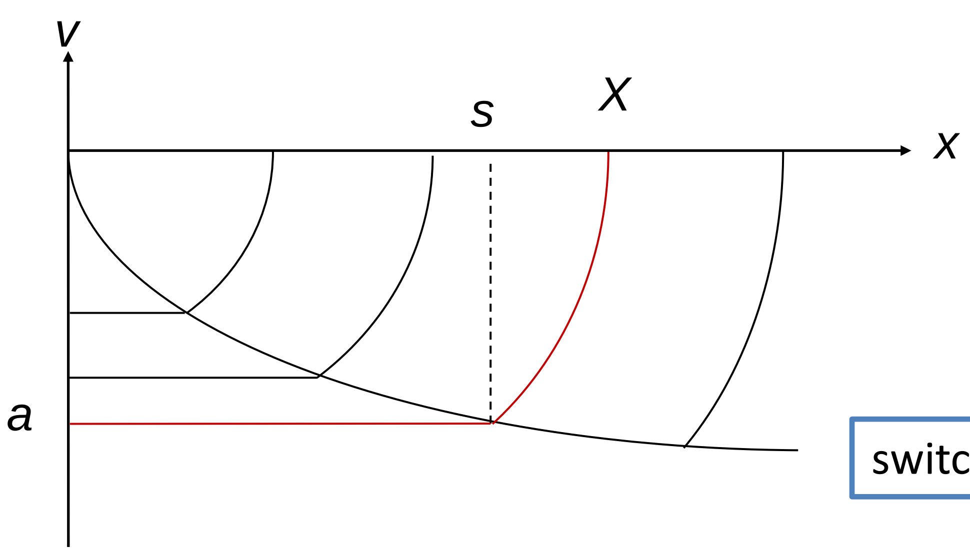
$$\frac{d}{dt}\left[z(t)x(t)\right] = z\dot{x} + \dot{z}x$$

where $z \equiv \dfrac{dJ^*(x_0)}{dx_0}$ marginal value of state

SWITCHING CURVE

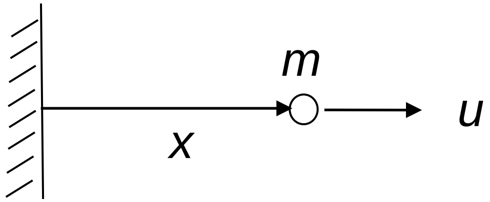
coasting line, a

$$s = -\frac{m}{k} a^3$$



switching curve, s

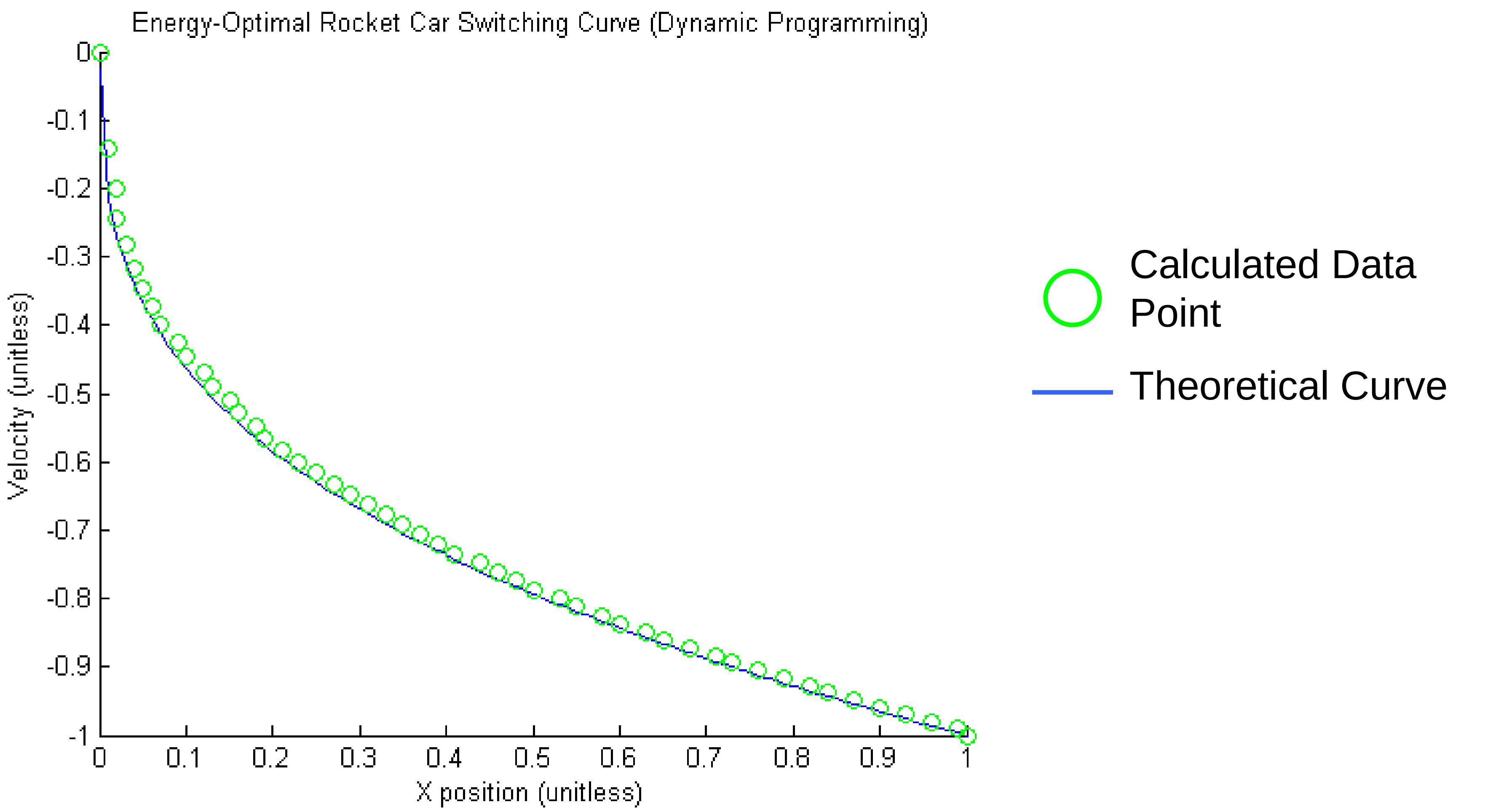
Positioning Problem



$$J = \int_0^T (k + uv)\,dt$$

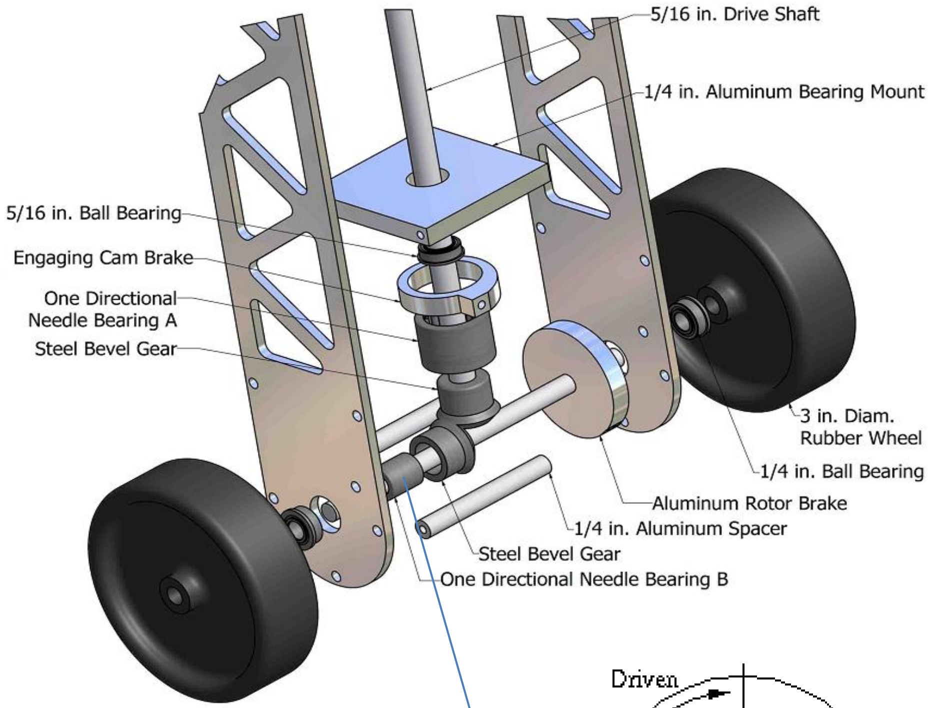
Time + energy cost

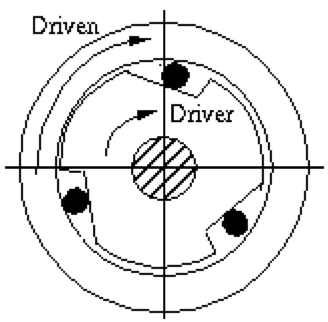
SWITCHING CURVE



HARDWARE IMPLEMENTATION

ROBOTIC SYSTEMS





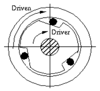
Overrunning clutch

Powered Phase

Motor CW

- Clockwise motion engages wheels

Free Spinning Phase



Motor off

- Unpowered motor enables this phase

Brake

Motor CCW

- Counterclockwise motion engages cam brake

FUTURE WORK

- Game theory approach to disturbances
- Sensor and Acuator uncertainty
- Dissipation

CONCLUSIONS

- Unmanned Systems allow for different optimization schemes (e.g. Mobility over Survivability)
- Legged Mobility still requires greater efficiency for real-world applications.
- GREAT PROMISE AND POTENTIAL usually requires GREAT EFFORT AND SACRIFICE to finish the job

- Thanks!